

# Liquid Scintillator Time Projection Chamber Concept

N. McConkey\*, Y.A. Ramachers

Department of Physics, University of Warwick,  
Coventry, CV4 7AL, UK

## Abstract

Results are presented from a small-scale experiment to investigate the use of room temperature organic liquid scintillators as the active medium for a time projection chamber (TPC). The optical properties of liquid scintillators have long been known, but their ability to transport charge has remained, until now, largely untested. The idea of using room temperature liquids as an active medium for an ionisation chamber was first presented in [1]. Since then the range of liquid scintillators available has been greatly developed. We present successful transport of ionization charges in a selection of both, pure organic liquid solvents and liquid scintillator cocktails over 20 mm using a variety of electric drift field strengths. The target of this research is to offer a cost effective alternative to liquid noble gas detectors in neutrino physics.

## 1 Introduction

A detector capable of delivering the neutrino physics program of the future will need to be extremely large in target mass, but also have fine grained tracking across the whole volume. A liquid argon time projection chamber fits these criteria well, and has been very successfully demonstrated to work at the 600 ton scale by ICARUS [2]. In terms of practicality, however, there are a number of drawbacks to using cryogenic liquids on a scale larger than this, i.e. the 100kton size that is aimed for in neutrino physics. Both the cryogenic infrastructure and the difficulty of purification to the high degree needed prove challenging.

We propose to consider the possibility of a room temperature liquid with scintillation properties similar to liquid argon, i.e. modern organic liquid scintillators.

### 1.1 History

The first observations of the presence of free electrons in a room temperature liquid were made in 1968, in neopentane [3], and tetramethylsilane [4], but it was not until the early '80s that these liquids were tested further, in the context of a liquid ionisation chamber [1], [5]. Tetramethylsilane (TMS) and tetramethyltin (TMT) were considered as potential candidates for the detector medium. These chemicals in particular were chosen due to the compact and spherical shape of the molecules. Theory suggested that mobility was inversely proportional to the length of the molecular chain [6], therefore these compact molecules were likely to have more useful charge transport properties.

### 1.2 Organic Liquid Scintillators and Solvents

In the past 20-30 years there has been a lot of development in organic liquids for scintillation counting applications. There are now many “safe” solvents produced, some of which are widely used in particle

---

\*Corresponding author: n.mcconkey@warwick.ac.uk

physics. Linear alkyl benzene (LAB) is used in the SNO+ [7], Daya bay [8] and RENO [9] experiments, phenyl xylyl ethane (PXE) was considered to be used in Borexino[10]. Di isopropyl naphthalene (DIN) has not been used in any particle physics experiments, but is a solvent especially designed for scintillation counting [11], and has optical properties comparable to the other solvents mentioned.

If any one of these liquids is found to be a suitable material for use in a time projection chamber, the room temperature operation would allow many practical benefits. The infrastructure would be much more straightforward than a system incorporating cryogenics, and there is already expertise in cleaning organic liquids to a high level of purity [7].

Whilst a large volume detector is necessary for long baseline neutrino experiments, a liquid scintillator TPC could also have a part to play in the search for neutrinoless double beta decay. Loading with isotopes is, again, well researched in organic liquid scintillators. With a large volume loaded liquid scintillator TPC, it would be possible to combine both high masses and fine grain tracking for double beta decay searches, a merger of the SNO+ [7] and SuperNEMO [12] concepts.

### 1.3 Feasibility

There are many measurements which need to be made in order to determine whether organic liquid scintillators represent a viable alternative to cryogenic liquids for use in TPCs, but the initial task is to investigate whether or not they can transport charge in any practically relevant manner.

For this purpose a gridded ionisation chamber was constructed, with an initial drift distance of 22 mm. An Am 241 alpha source is mounted at the cathode, and a Frisch grid, mounted 7 mm from the readout anode is resistively coupled to the anode, keeping the ratio of the two electric fields constant at 53:50, which makes the grid optically transparent to drifting electrons [13]. The measurements presented here are the first results from the measurement programme using this detector.

## 2 Selected Results






Chemical name	Chemical Formula	Molecule structure
Di isopropyl naphthalene (DIN)	$C_{16}H_{20}$	
Mono isopropyl naphthalene (MIPN)	$C_{16}H_{14}$	
Mono isopropyl biphenyl (MIBP)	$C_{15}H_{16}$	
Linear alkyl benzene (LAB)	$C_6H_5C_{10}H_{21}$ to $C_{13}H_{27}$	
Phenyl xylyl ethane (PXE)	$C_{16}H_{18}$	

Table 1: The organic liquids and solvents tested and their molecular structure.

### 2.1 Di isopropyl naphthalene (DIN)

Two types of di isopropyl naphthalene have been tested, both the pure solvent, and an off-the-shelf scintillation cocktail, i.e. DIN with wavelength shifting fluors added.

The event rate measurements from the two liquids are strikingly different; the pure liquid has about twice the number of events than measured in the scintillation cocktail, for any given drift field. This suggests that the presence of the fluors in the liquid has a detrimental effect on the charge transport properties of the liquid.

The drift speed in DIN was measured to be  $(101 \pm 2) \text{ ms}^{-1}$  in a drift field of  $6.93 \text{ kVcm}^{-1}$ , as shown in Figure 1. This is approximately a factor of 20 slower than the corresponding drift speed in liquid argon [14], see discussion below.

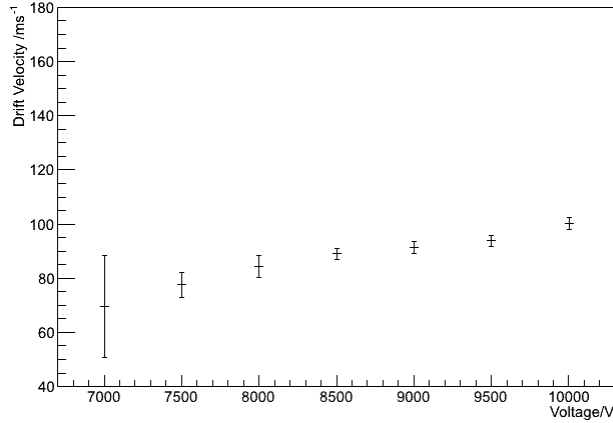


Figure 1: Drift speed as a function of voltage, in di isopropyl naphthalene (DIN).

## 2.2 Mono isopropyl naphthalene (MIPN)

Mono isopropyl naphthalene is an organic solvent with similar chemical structures and properties to DIN, although it is not a commonly used liquid for scintillation counting. The drift speed of MIPN as a function of drift voltage is shown in Figure 2. At an electric field of  $6.93 \text{ kVcm}^{-1}$ , the drift speed has been measured to be  $(143 \pm 9) \text{ ms}^{-1}$ .

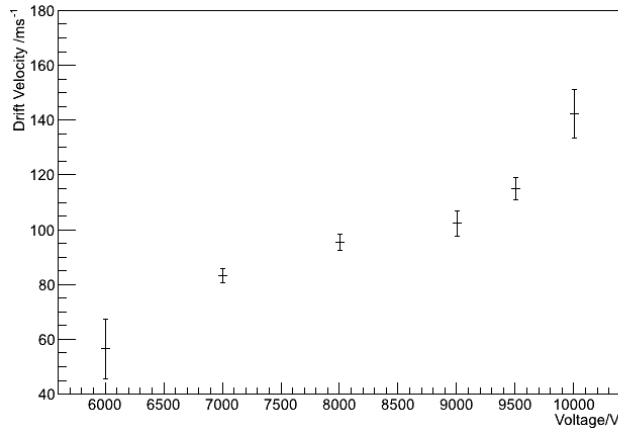


Figure 2: Drift speed as a function of voltage, in mono isopropyl naphthalene (MIPN).

## 2.3 Mono isopropyl biphenyl (MIBP)

Mono isopropyl biphenyl is an organic solvent which is also not used for scintillation counting, therefore its optical properties are currently unknown, but its chemical similarity to DIN warranted testing.

The drift speed of MIBP as a function of drift voltage is shown in Figure 3. At a drift field of  $7.63 \text{ kVcm}^{-1}$ , the drift speed has been measured to be  $(156 \pm 6) \text{ ms}^{-1}$ .

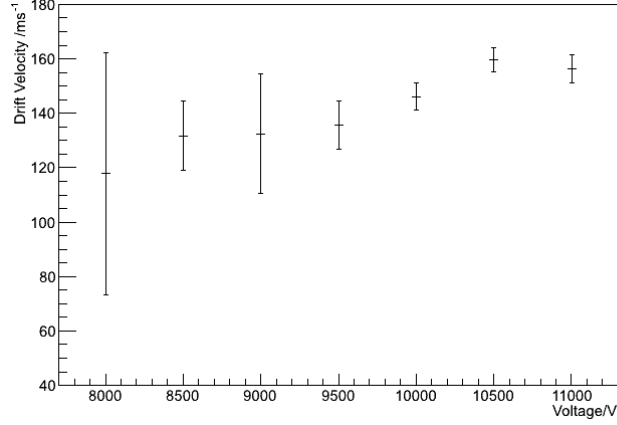


Figure 3: Drift speed as a function of voltage, in mono isopropyl biphenyl (MIBP).

## 2.4 Linear alkyl benzene (LAB)

The solvent linear alkyl benzene has been obtained with scintillation fluors pre-mixed. It has been found that although charge transport is possible in LAB, the dielectric strength of the material is much lower than the other solvents tested, therefore it is not possible to reach the electric fields needed in order to drift charge at a measurable speed.

It is also suggested [6] that the molecular shape (see Table 1) of LAB would not correspond to one which would have a high mobility, and therefore the low event rates recorded (see Figure 4) are due to the nature of the solvent as well as the fluors present.

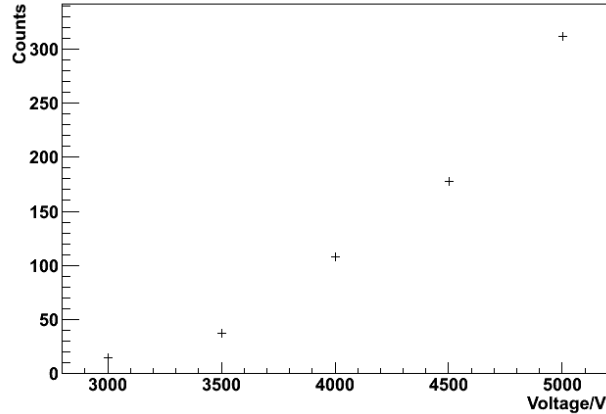


Figure 4: The event rate in linear alkyl benzene as a function of drift voltage. Note the relatively low applied maximum bias before onset of sparking in this liquid.

## 2.5 Phenyl xylyl ethane (PXE)

The solvent phenyl xylyl ethane has been obtained with scintillation fluors premixed. The liquid has been found to break down at voltages above 10kV (see Figure 5). The plateau between 7 and 8kV, with a low event rate seems promising; it is possible that as in DIN, the fluors are reducing the event rate. It is intended to source this PXE as a pure solvent without fluors for further testing.

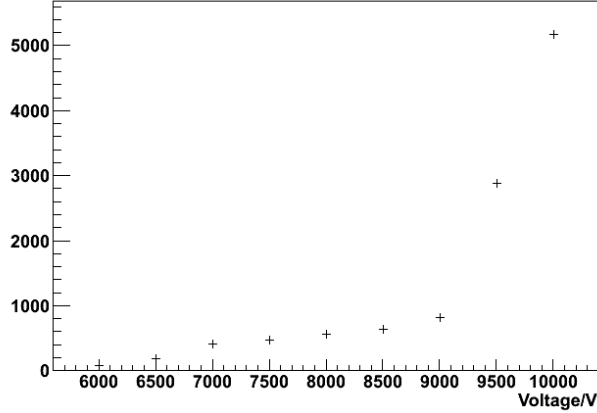


Figure 5: The event rate in phenyl xylyl ethane as a function of drift voltage.

## 3 Conclusions

With the exception of LAB, all tested solvents and cocktails are able to transport charge. This discovery gives a clear way forward; a measurement program to fully characterise their transport properties.

A drift speed of roughly a factor 20 less than the typical drift speed observed in liquid argon detectors at around 0.5 to 1 kV/cm drift field strength does not invalidate detector operation for room-temperature liquids. The only direct consequence would be a constraint on permissible total event rates which need to be kept low generally for rare event searches such as neutrino detection anyway. However, low drift speed suggests low mean free paths for charge transport for the simple reason that charges should have a higher probability to be trapped by impurities the longer they travel in the liquid. This mean free drift length will be addressed in our measurement programme in the near future.

The preliminary drift velocities will be refined, and the mean free path measured, as the drift distance in the current setup is increased up to 100 mm. It is planned to implement a pulsed photo-conversion electron source. With the advent of cheap and fast UV LED light sources [15], such a source is expected to permit precision control of charge-pulse production in our setup. It is also necessary to characterise fully the scintillation properties for each solvent as opposed to commercial cocktails, using for instance optical spectroscopy in the UV spectral range.

This further work will determine whether or not the organic liquids presented will prove a viable alternative to cryogenic liquids for use in large volume TPCs with far reaching consequences for neutrino physics.

## References

- [1] J. Engler and H. Keim *A Liquid Ionisation Chamber using Tetramethylsilane*, Nucl.Instrum.Meth. **A 223** (1984) 47-51
- [2] C. Rubbia et al., *Underground operation of the ICARUS T600 LAr-TPC: first results*, JINST **6** (2011) P07011
- [3] P.H Tewari and G.R. Freeman, *Dependence of Radiation Induced Conductance of Liquid Hydrocarbons on Molecular Structure*, J Chem. Phys. **49** (1968) 4394
- [4] R. A. Holroyd and Mark Allen, *Energy of Excess Electrons in Nonpolar Liquids by Photoelectric Work Function Measurements*, J. Chem. Phys **54** (1971) 5014
- [5] R. A. Holroyd and D. F. Anderson, *The Physics and Chemistry of Room-temperature liquid-filled ionisation chambers*, Nucl.Instrum.Meth. **A 236** (1985) 294-299
- [6] I. Adamczewski and J. H. Calderwood, *The mobility of fast charge carriers in liquid paraffins and its dependence on molecular structure*, J. Phys. D: Appl. Phys. **9** (1976) 2479-2483
- [7] R. Ford et al., *SNO+ scintillator purification and assay*, AIP Conf.Proc. **1338** (2011) 183-194
- [8] F.P.An et al. [Daya Bay Collaboration], *A side-by-side comparison of Daya Bay antineutrino detectors*, arXiv:1202.6181 [physics.ins-det].
- [9] J. K. Ahn et al. [RENO Collaboration], *Observation of Reactor Electron Antineutrino Disappearance in the RENO Experiment*, Phys. Rev. Lett. **108** (2012) 191802 [arXiv:1204.0626 [hep-ex]].
- [10] H. O. Back, et al., *Study of phenylxylylene (PXE) as scintillator for low energy neutrino experiments*, Nucl.Instrum.Meth. **A 585** (2008) 48-60
- [11] J. Thomson, *Proceedings of the International Conference on New Trends in Liquid Scintillation Counting and Organic Scintillators*, Proceedings of the International Conference on New Trends in Liquid Scintillation Counting and Organic Scintillators, Ch.3 (1989) 19-33
- [12] Barabash, A.S., *SuperNEMO double beta decay experiment*, Preprint arXiv:1112.1784 (2011); <http://arxiv.org/abs/1112.1784v2>
- [13] E. Buckley et al., *A study of ionization electrons drifting over large distances in liquid argon*, Nucl.Instrum.Meth. **A 275** (1989) 364-372
- [14] E. Aprile et al., *Noble Gas Detectors*, Wiley-VCH, 2006.
- [15] K. Valerius et al., *A UV LED-based fast-pulsed photoelectron source for time-of-flight studies*, New J. Phys. **11** (2009) 063018